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Adaptation to climate change via adjustment in land leasing: Evidence from dryland wheat farms in the U.S. Pacific Northwest

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ABSTRACT

Land leasing is a possible climate adaptation where risk is shared. We investigate how climate affects dryland wheat farmland rental patterns in the U.S. Pacific Northwest. Using farm-level agricultural census data, we study the relationships between climate and leasing arrangements. We find that increases in precipitation reduce leased land and increase the use of cash-rent leases, while increases in precipitation variability reduce the prevalence of cash-rent leases. Using medium and high greenhouse-gas emission-based climate projections we predict that, by 2050, leased acreage will decline by 23% and, respectively 29%.

1. Introduction

Climate change is happening with increases in temperature, precipitation variability and extreme weather event frequency being observed and such trends are expected to continue to evolve (IPCC, 2014). Climate have been found to influence actions and outcomes in the agricultural sector, including livestock production, crop yields, food security, farm profitability, farmland value and land use (as reviewed in IPCC, 2014 and Dell et al., 2014).

Although subsistence farms in developing countries are likely to be most vulnerable to climate change, impacts of climate change on developed countries such as the United States (US) are also important to consider for the world agricultural market. For example, over 20 percent of US agricultural production was exported in 2015–2017, including 46 percent of wheat production.[1] Furthermore, the agricultural sector makes an important contribution to the US economy especially local economies in rural areas with 11 percent of 2015 total US employment occurring in the agricultural and food sectors.[2]

A growing body of literature has examined potential adaptations to climate change through changes in management practices and policies, e.g., planting dates, irrigation technologies, crop insurance, agricultural land use, cropping systems and fallow rotation (Negri et al., 2005; Smith et al., 2007; Ortiz-Bobea and Just, 2013; Smith et al., 2014; Annan and Schlenker, 2015; Olen et al., 2016; McCarl et al., 2016; Antle et al., 2017; Mu et al., 2017; Zhang et al., 2017). A less studied possible adaptation involves use of land leasing (Eskander and Barbier, 2016) which is a means of sharing production risk with landowners. Climate may influence the extent of leasing and the type of lease arrangements. According to the 2012 Census of Agriculture, 78% of dryland wheat farms in the U.S. Pacific Northwest region leased some land, among which 74% had cash rent leases and 69% crop share leases (some farms used a mixture of both). Leasing contracts tradeoff between risk-sharing and incentives (Cheung, 1968; Stiglitz, 1974; Otsuka et al., 1992) and different forms differ in transaction costs and extent of risk transfer (Allen and Lueck, 1992).

Issues in agricultural land leasing markets have been studied with focuses on property right insecurity (Myyrä et al., 2005; Maddison, 2007; Yegbemey et al., 2013), land tenancy (Paulson and Schnitkey, 2013), rental contact choice (Qiu et al., 2011; Bryan et al., 2015), and farmland rental rates (Breustedt and Habermann, 2011; Ciaian and Kancs, 2012; Kirwan and Roberts, 2014). Eskander and Barbier (2016) did a study linking climate influences finding in Bangladesh that

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[1] Data are available at https://www.fas.usda.gov/data/percentage-us-agricultural-products-exported. Accessed on June 14, 2018.
[2] Data are available at https://www.ers.usda.gov/data-products/chart-gallery/gallery/chart-detail/?chartId=58282. Accessed on June 14, 2018.

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farmers' reliance on leased land increases as losses from floods and storms rise. However, their study only narrowly treated climate and thus did not reveal how land leasing decisions adjust in response to temperature and precipitation as well as their variability which we address in this analysis.

To do this, we use US Census of Agriculture farm-level land leasing data for Pacific Northwest (PNW) dryland wheat farms. We examine leasing responses to 5-year average growing season precipitation and temperature as well as climate variability including effects on type of lease. We then predict changes in leased acreage by 2050 based on climate projections under two greenhouse-gas emission scenarios.

2. Theoretical framework

The principal-agent model can be used to analyze climate effects on land rental markets and we use it to explore choice of rental market participation and leasing arrangements. In doing this we assume that the principal, i.e., a landowner, and the agent, i.e., a tenant, are both risk-averse. Following Huffman and Just (2004), the tenant's production on a unit land is a stochastic function,

$$y(e) = \mu e + \varepsilon, \tag{1}$$

where y is the yield per unit land, e is tenant effort that is unobservable to landowners, μ is land productivity, and ε is a random shock with a mean of zero and a variance of σ^2 (e.g., weather-related risk). A rise in μ implies an increase in production, while a rise in σ^2 implies an increase in the production uncertainty. Climate can alter both μ and σ^2 influencing average productivity and its variance.

Suppose in the land market a landowner offers a linear incentive contract to a potential tenant (Stiglitz, 1974),

$$w = \alpha p y - \beta, \tag{2}$$

where w is the total payment received by the tenant, α is the share of output received by the tenant ($0 \leq \alpha \leq 1$), p is the output price, and β is a cash payment. Note that the parameter β is not necessarily positive: if β is negative, then the landowner pays either a cash wage or part of the costs borne by the tenant; alternatively, if β is positive, the tenant pays a cash rent to the landowner. When $\alpha = 1$ and $\beta > 0$, the contract represents a pure fixed cash-rent system; thus, the contract moves toward a pure cash-rent system as α goes up. In contrast, a contract with $\alpha > 0$ and $\beta < 0$ is a crop share where the tenant retains part of the output and the landowner pays part of the costs of production. Other forms of rental contracts are possible.

Following Huffman and Just (2004), suppose the tenant's cost of farming is a quadratic function of effort (e), $0.5ke^2$, with k representing a tenant-specific parameter. Then, the net return received by the tenant (π^T) is,

$$\pi^T(e) = w - 0.5ke^2. \tag{3}$$

Combining Eqs. (1)–(3), the tenant's expected net return is $E[\pi^T(e)] = \alpha\mu pe – \beta – 0.5ke^2$, and the variance of the expected net return is $Var(\pi^T(e)) = \alpha^2 p^2 \sigma^2$. Now we assume tenant has a smooth and twice differentiable utility function (U^T). The tenant's problem is to choose the optimal effort for maximizing expected utility, which can be approximated by a linear mean-variance utility function (Just and Zilberman, 1983),

$$\begin{aligned} &Max_e E[U^T(\pi^T(e))]. \\ &= Max_e E[\pi^T(e)] - 0.5r^T Var(\pi^T(e)) \\ &= Max_e \alpha\mu pe - \beta - 0.5ke^2 - 0.5r^T\alpha^2p^2\sigma^2 \end{aligned} \tag{4}$$

where r^T is the tenant's risk aversion coefficient. The tenant's optimal effort (e^*) is derived from the first-order condition of Eq. (4),

$$e^* = \alpha\mu p/k. \tag{5}$$

Substituting the Eqs. (5) into (4), we obtain the tenant's maximum expected utility,

$$E[U^T(\pi^T(e^*))] = 0.5\alpha^2p^2\left(\frac{\mu^2}{k} - r^T\sigma^2\right) - \beta. \tag{6}$$

The landowner's net return from the contract is,

$$\pi^L(\alpha, \beta) = (1 - \alpha)py + \beta, \tag{7}$$

Similar to the tenant, assume the landowner has a smooth and twice differentiable utility function (U^T). The landowner maximizes the expected utility function that can be approximated by a mean-variance utility function,

$$\begin{aligned} &Max_{\alpha,\beta} E[U^L(\pi^L)] \\ &= Max_{\alpha,\beta} E[\pi^L] - 0.5r^L Var(\pi^L) \\ &= Max_{\alpha,\beta}(1 - \alpha)\mu pe + \beta - 0.5r^L(1 - \alpha)^2p^2\sigma^2. \end{aligned} \tag{8}$$

In turn, the tenant will accept the incentive contract offered by the landowner in Eq. (2) if the contract satisfies incentive compatibility and voluntary participation conditions. With incentive compatibility, the landowner is assumed to choose the contract under which the tenant chooses his optimal effort in Eq. (5). With voluntary participation, the expected net return received by the tenant from the contract is at least as large as the tenant's reserved utility (u^R). Assuming that the reservation utility is equal to the maximized expected utility as given by (6), the cash rent paid by the tenant can be expressed as

$$\beta = 0.5\alpha^2p^2\left(\frac{\mu^2}{k} - r^T\sigma^2\right) - u^R. \tag{9}$$

Combining Eq. (8) with the incentive compatibility constraint (5) and voluntary participation constraint (9), the landowner's problem can be rewritten as,

$$Max_\alpha (1 - \alpha)\alpha\frac{\mu^2p^2}{k} + 0.5\alpha^2p^2\left(\frac{\mu^2}{k} - r^T\sigma^2\right) - u^R - 0.5r^L(1 - \alpha)^2p^2\sigma^2. \tag{10}$$

The optimal share of the output received by the tenant is derived from the first-order condition of Eq. (10),

$$\alpha^* = \frac{\frac{\mu^2}{k} + r^L\sigma^2}{\frac{\mu^2}{k} + (r^T + r^L)\sigma^2}, \tag{11}$$

and substituting Eq. (11) into Eq. (9) obtains the optimal cash payment received by the tenant,

$$\beta^* = 0.5\left[\frac{\frac{\mu^2}{k} + r^L\sigma^2}{\frac{\mu^2}{k} + (r^T + r^L)\sigma^2}\right]^2 p^2\left(\frac{\mu^2}{k} - r^T\sigma^2\right) - u^R \tag{12}$$

For the purpose of this study, we focus on climate impacts on land rental market participation and farmland leasing arrangements through land productivity (μ) and production certainty (σ^2). From Eqs. (11) and (12), we obtain the following relationships:

$$\frac{d\alpha^*}{d\mu} > 0, \frac{d\alpha^*}{d\sigma^2} < 0, \frac{d\beta^*}{d\mu} > 0, \frac{d\beta^*}{d\sigma^2} < 0. \tag{13}$$

Here increases in land productivity (μ) increase the share of crop received by the tenant and results in the contract moving toward a cash rental contract. In contrast, increases in production uncertainty reduces the share of crop received by the tenant and results in the contract moving toward a crop share contract. In terms of rental market

participation, increases in land productivity increases amount paid by the tenant and thus less farmland will be leased. In contrast, increases in production uncertainty reduces cash rent and thus more farmland will be leased.

From Eq. (13) we hypothesize that if climate increases land productivity or reduces production uncertainty, less farmland will be leased and leasing terms will move toward cash rent. In contrast, if climate decreases land productivity or increases production uncertainty, then more farmland will be leased and terms will move toward a crop share contract. We examine these hypotheses in our empirical analysis below.

3. Estimation strategy

We apply the spatial analogue approach (Adams et al., 1998) in a panel data form to estimate climate effects on leased acreage and leasing arrangements. The spatial analogue approach relies on climate induced variations in leasing over space and time as climate shifts to identify climate effects. Therein we use spatial and temporal variation in climate and leasing to identify climate's effects on leased farmland acreage and leasing arrangements. In this study, the amount of leased farmland acreage is estimated by a pooled ordinary-least-squares regression,

$$A_{it} = \alpha_0 + \theta_{st} + f(\mathbf{c}_{it}, \boldsymbol{\beta}_0) + \boldsymbol{\gamma}_0 \boldsymbol{X}_{it} + \boldsymbol{\delta}_0 \boldsymbol{e}_i + \varepsilon_{it}, \quad (14)$$

where i represents an individual wheat farm, t is census year, and s indicates the state where farm i is located. A_{it} is the acreage of leased farmland on farm i in year t. $\mathbf{c}_{it}$ is a vector of climate conditions. $\boldsymbol{X}_{it}$ is a vector of socioeconomic variables that characterize farm operator i (these characteristics are discussed below). $\boldsymbol{e}_i$ is a vector of soil variables for the region where farm i is located. θ_{st} is a state by year fixed effect, and ε_{it} is a disturbance term. $f(\bullet)$ is a functional form for the influence of climate variables.

The choice of farmland leasing arrangements is estimated by a multinomial logit model,

$$Prob(D_{it} = j \mid A_{it} \rangle 0) = \frac{\exp[\alpha_j + \theta_{stj} + f(\mathbf{c}_{it}, \boldsymbol{\beta}_j) + \boldsymbol{\gamma}_j \boldsymbol{X}_{it} + \boldsymbol{\delta}_j \boldsymbol{e}_i]}{\sum_{k=1}^{3} \exp[\alpha_j + \theta_{stj} + f(\mathbf{c}_{it}, \boldsymbol{\beta}_k) + \boldsymbol{\gamma}_k \boldsymbol{X}_{it} + \boldsymbol{\delta}_k \boldsymbol{e}_i]}, j = 1, 2, 3. \quad (15)$$

where j represents a type of rental contracts (i.e., a pure cash-rent contract, a pure crop-sharing contract, and a hybrid contract mixing cash rent and crop sharing). D_{it} is the choice of the type of rental contract on farm i in year t.

We use the spatial analogue approach because we cannot observe a large enough range of changes in climate at a given farm to cover the range of change projected in the climate change projections. Thus, we use data on land leasing over space and time where climate conditions across the sample show a wide enough variation over space to infer acreage responses of leased farmland to future climate based on our panel dataset. Naturally this implies we control for the other factors that vary over space and we do this through use of soil characteristics, farmers characteristics and the year-by-state fixed effects in the cross-sectional estimation. The spatial analogue approach has been commonly applied in the climate change impact assessment literature to address such an issue (e.g., Mendelsohn et al., 1994; Lobell et al., 2007; McCarl et al., 2008; Schlenker and Roberts, 2009; Mu et al., 2013).

To capture the fact that some farmland is limited by cold or dryness while others by heat or wetness we allow a non-linear response to climate with a possible critical point below and above which the nature of responses changes. To do this we estimate Eqs. (13) and (14) with a quadratic specification for the climate variables, $f(\bullet)$. We also know leasing is often a longer term phenomena and feel that it will not change rapidly in response to year-to-year changes in climate. Thus we use 5-year moving averages for the climate variables to reflect shifts in longer term persistent conditions. We include these 5-year averages for growing season total precipitation and average temperature as well as climate variability measures for precipitation and temperature in the form of the moving 22-year coefficients of variation.

In drawing the sample we only examine dryland farms. Irrigated farms are not considered because we cannot control for important non-climate factors such as economic and physical water scarcity and water supply institutions (Olen et al., 2016) plus we feel the irrigated response to climate will differ from the dryland one. Additionally, we do not feel local climate variables are the only ones to include as much of the irrigation water arises from distant locales (upriver somewhere for surface water irrigation as further discussed in Schlenker et al., 2005).[3]

We exclude wheat prices in our estimation and use state-by-year fixed-effects to capture common contemporaneous factors like regional transport patterns affecting prices and varying crop prices temporally.[4] Also, the objective of this paper is to estimate the amount of leasing response function and choice of leasing types, i.e., total climate influences, rather than supply functions that require output and input prices.

4. Data

The study area is the PNW states of Oregon, Washington and Idaho. The US Census of Agriculture for the years 2002, 2007 and 2012 is the main data source (National Agricultural Statistics Service (USDA), 2018 National Agricultural Statistics Service 2002, 2007, 2012). We use data on dryland wheat farms which have more than 50 acres of land. The resultant data set covers 9925 dryland wheat farms over the three census years. Census data used include land leased, proportion of land enrolled in CRP and WRP programs, size of farm sales indicating whether they are under or over $250,000, farming experience and farming occupation. Panel A in Table 1 reports summary statistics on these variables.

Soil data come from the Gridded Soil Survey Geographic (gSSURGO) database (Natural Resources Conservation Service, 2015). ZIP code level soil variables are generated by taking the acreage-weighted average across all gSSURGO polygons within the ZIP code. Soil variables used are land slope, amount of soil organic matter, sand and clay contents, and soil loss tolerance factor. Panel B in Table 1 reports summary statistics on these soil variables. We use farm ZIP code to link the farm data to the soil and climate data.

Weather data are drawn Abatzoglou and Brown (2012)'s gridded dataset with 4-km resolution. We compute the 5-year moving average on total precipitation and average temperature over the September-June winter wheat growing season at the ZIP code level. We also develop climate variability measures in terms of coefficients of variation for the growing season total precipitation and average temperature over 22 years. Panel C in Table 1 reports summary statistics for these items.

[3] Irrigation water allocation is governed by the doctrine of prior appropriation in the US Pacific Northwest, which is a seniority-based water allocation system. Irrigators need to apply for an irrigation water right before withdrawing water, and it usually takes several years to get such application approved. After getting a water right, irrigators need to prove and verify their use of irrigation water. Also, water markets in the study region are less active than those in the rest of the Western US. Thus, climate will have a minimal effect, if any, on dryland farms through irrigation.

[4] The main justification for invariant wheat prices within state in a given census year is that wheat is a major field crop whose price is the determined by the global market; thus, wheat prices are set at the global level and invariant over space in a given census year. In the US Pacific Northwest region wheat prices are only available at the state level, and there is no price information at a disaggregate level such as farm. For example, the 2012 wheat prices in the states of Idaho, Oregon and Washington are 7.92, 8.10 and 8.07 dollars per bushel according to the United States Department of Agriculture 2012 survey data (United States Department of Agriculture (USDA, 2012).

Table 1
Summary statistics on US PNW data.

	2002		2007		2012		Variable Description
	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.	
Panel A							
Land leased	1.32	2.28	1.53	2.15	1.49	2.20	Leased farmland acreage (1000 acres)
CRP and WRP programs	0.08	0.30	0.08	0.18	0.07	0.15	Share of cropland under CRP and WRP programs
Classified as large farm	0.43	0.50	0.62	0.48	0.68	0.47	Total farm revenue of over $250,000 (1 = yes, 0 = no)
Farming experience	24.55	13.72	26.40	13.96	27.44	14.19	Farming experience (years)
Farming occupation	0.91	0.29	0.87	0.33	0.88	0.33	Operator occupation (1 = farming, 0 = employed off-farm)
Panel B							
Slope	17.21	8.34	17.17	8.19	16.49	8.43	Average land slope in percent
Soil organic content	9.71	4.50	9.42	4.41	9.95	4.70	Soil organic content in top one meter (kg C/m^2)
Sand content	23.39	10.61	23.94	11.27	23.61	10.99	Percent of particles with 0.05-2 mm in diameter
Clay content	16.58	6.15	16.12	5.92	17.04	6.54	Percent of particles with < 2 mm in diameter
Soil loss tolerance factor	3.82	0.69	3.82	0.69	3.82	0.68	Soil loss tolerance factor (tons/acre/year)
Panel C							
Precipitation	20.84	11.36	17.89	8.98	20.52	11.53	5-year average of growing season total precipitation (inch)
Average Temperature	7.28	1.58	7.52	1.54	6.99	1.67	5-year average of growing season average temperature (°C)
CV Precipitation	4.90	0.79	4.91	0.75	4.95	0.81	Coefficient of variation of total precipitation
CV Ave. Temperature	9.81	3.50	9.82	3.14	11.37	3.47	Coefficient of variation of average temperature
Number of observations	3815		3025		3085		

Notes: All climate variables are computed over the growing season from September to June (inclusive).

Table 2
Marginal effects on leased farmland acreage and contract choice.

Variables	(1) Land leased in 1000 acres	(2) Choice of cash-rent contract	(3) Choice of hybrid contract	(4) Choice of crop-share contract
Precipitation	−0.0439***	0.0034***	0.0024	−0.0059***
	(0.0085)	(0.0010)	(0.0017)	(0.0016)
Temperature	−0.1243	0.0046	−0.0014	−0.0032
	(0.0998)	(0.0112)	(0.0155)	(0.0133)
C.V. precipitation	−0.0883	−0.0150**	0.0167*	−0.0017
	(0.0536)	(0.0061)	(0.0087)	(0.0075)
C.V. temperature	0.0736	0.0048	−0.0036	−0.0012
	(0.0550)	(0.0059)	(0.0083)	(0.0073)
CRP and WRP programs	0.1012	0.0155	−0.0861***	0.0706***
	(0.0780)	(0.0195)	(0.0301)	(0.0208)
Large farm	1.5392***	−0.0709***	0.1058***	−0.0349***
	(0.0687)	(0.0079)	(0.0109)	(0.0094)
Farming experience	−0.0087***	0.0002	−0.0000	−0.0002
	(0.0016)	(0.0003)	(0.0004)	(0.0003)
Farming occupation	0.4068***	−0.0177	0.0436***	−0.0259*
	(0.0498)	(0.0125)	(0.0168)	(0.0138)
Slope	0.0027	−0.0001	−0.0013	0.0014*
	(0.0049)	(0.0006)	(0.0008)	(0.0007)
Soil organic carbon	−0.0225	0.0035*	−0.0009	−0.0026
	(0.0147)	(0.0019)	(0.0028)	(0.0025)
Sand content	−0.0025	0.0030***	0.0008	−0.0039***
	(0.0064)	(0.0005)	(0.0006)	(0.0005)
Clay content	−0.0143	0.0059***	0.0042**	−0.0101***
	(0.0101)	(0.0012)	(0.0018)	(0.0016)
Soil loss tolerance factor	−0.0845	−0.0265***	−0.0094	0.0359***
	(0.0780)	(0.0085)	(0.0117)	(0.0099)
Observations	9925	9,507	9,507	9,507

Notes: All models include state-by-year fixed effects. A hybrid contract is a mixed contract including both cash rent and crop sharing. Standard errors in parentheses. *** p < 0.01, ** p < 0.05, * p < 0.1.

5. Estimation results and robustness checks

Eqs. (14) and (15) we estimated and the marginal effects of the climate and non-climate variables are given in Table 2. Column (1) in Table 2 presents the results for amount of leased acreage for dryland wheat farms. Columns (2) - (4) present these variables' marginal effects on the probability of choosing a pure cash-rent lease, a hybrid lease (a mixture of both cash-rent and crop-share), and a pure crop-share lease given the land is leased. Table A1 in the Appendix A contains the coefficient estimates for the independent variables in Table 2.

5.1. Effects on amount of PNW dryland wheat leased land

The results (Column (1) in Table 2) show a significant, negative marginal effect of precipitation on leased acreage. A one-inch precipitation increase reduces leased land by 44 acres. As indicated in the Eq. (13), this can be explained by the fact that increased moisture improves crop productivity, which increases land rent and hence reduces leased acreage. The detailed coefficient estimates (Table A1) show a non-linear relationship between precipitation and leased acreage. This reflects the fact that rising precipitation increases productivity in dry areas but with diminishing effects rising up to a point where there is too much moisture then productivity falls.

Since most of the farms are located in relatively cool climate areas, the marginal effect of temperature on leased farmland acreage is negative though statistically insignificant as shown in column (1) of Table 2. This result is intuitive because warmer climate is beneficial for winter wheat production preventing from winterkills and thus improves crop productivity and land profitability, resulting in higher land rent and less leased acreage.

5.2. Effects on leasing terms

Now we focus on climate influences on the choice of leasing arrangements. Columns (2)-(4) in Table 2 shows that precipitation has a significant positive effect on the probability of farmers choosing pure cash-rent contracts and a significant negative effect on crop-share contracts. As indicated in Eq. (13), increases in precipitation increase land productivity and hence move the contract toward a pure cash-rent.

Precipitation variability shows a significant negative effect on the

Table 3
Marginal effects of covariates on leased farmland acreage, robustness check.

Dependent variables	Farms with production contract	Farms without production contract				22-year moving averages of climate variables			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Land leased in 1000 acres	Land leased in 1000 acres	Choice of cash-rent contract	Choice of hybrid contract	Choice of crop-sharing contract	Land leased in 1000 acres	Choice of cash-rent contract	Choice of hybrid contract	Choice of crop-sharing contract
Independent variables									
Precipitation	−0.056**	−0.045***	0.0027***	0.0040**	−0.0068***	−0.043***	0.0027**	0.0040**	−0.0067***
	(0.024)	(0.008)	(0.0011)	(0.0018)	(0.0017)	(0.009)	(0.0011)	(0.0018)	(0.0017)
Temperature	−0.506**	−0.083	0.0021	0.0054	−0.0075	−0.113	−0.0072	0.0063	0.0009
	(0.255)	(0.094)	(0.0117)	(0.0165)	(0.0144)	(0.106)	(0.0117)	(0.0170)	(0.0150)
C.V. precipitation	−0.141	−0.083*	−0.0134**	0.0132	0.0002	−0.085	−0.0111*	0.0111	0.0000
	(0.194)	(0.049)	(0.0063)	(0.0091)	(0.0080)	(0.055)	(0.0063)	(0.0092)	(0.0081)
C.V. temperature	0.176	0.071	0.0072	−0.0077	0.0005	0.065	0.0115*	−0.0076	−0.0039
	(0.133)	(0.052)	(0.0062)	(0.0089)	(0.0079)	(0.057)	(0.0061)	(0.0092)	(0.0083)
CRP and WRP programs	−0.077	0.098	0.0123	−0.0821***	0.0698***	0.105	0.0124	−0.0821***	0.0697***
	(0.285)	(0.084)	(0.0193)	(0.0315)	(0.0222)	(0.078)	(0.0193)	(0.0315)	(0.0222)
Large farm	1.471***	1.570***	−0.0611***	0.1072***	−0.0461***	1.539***	−0.0610***	0.1074***	−0.0464***
	(0.258)	(0.069)	(0.0083)	(0.0115)	(0.0101)	(0.069)	(0.0083)	(0.0115)	(0.0101)
Farming experience	−0.008	−0.009***	0.0001	−0.0001	−0.0001	−0.009***	0.0001	−0.0001	−0.0001
	(0.005)	(0.002)	(0.0003)	(0.0004)	(0.0003)	(0.002)	(0.0003)	(0.0004)	(0.0003)
Farming occupation	0.151	0.428***	−0.0257**	0.0551***	−0.0294**	0.409***	−0.0255**	0.0550***	−0.0296**
	(0.185)	(0.048)	(0.0129)	(0.0178)	(0.0148)	(0.050)	(0.0129)	(0.0178)	(0.0148)
Slope	0.023	0.000	−0.0002	−0.0013	0.0014*	0.003	−0.0002	−0.0013	0.0015*
	(0.019)	(0.004)	(0.0006)	(0.0009)	(0.0008)	(0.005)	(0.0006)	(0.0009)	(0.0008)
Soil organic carbon	0.055	−0.033**	0.0034*	−0.0005	−0.0029	−0.024	0.0026	−0.0002	−0.0024
	(0.052)	(0.013)	(0.0020)	(0.0029)	(0.0026)	(0.015)	(0.0020)	(0.0029)	(0.0027)
Sand content	0.011	−0.004	0.0036***	0.0008	−0.0043***	−0.003	0.0034***	0.0009	−0.0043***
	(0.020)	(0.006)	(0.0005)	(0.0007)	(0.0006)	(0.006)	(0.0005)	(0.0007)	(0.0006)
Clay content	−0.036	−0.011	0.0068***	0.0046**	−0.0114***	−0.014	0.0064***	0.0047**	−0.0111***
	(0.025)	(0.010)	(0.0013)	(0.0019)	(0.0018)	(0.010)	(0.0013)	(0.0019)	(0.0018)
Soil loss tolerance factor	−0.235	−0.066	−0.0278***	−0.0118	0.0396***	−0.084	−0.0252***	−0.0132	0.0383***
	(0.234)	(0.073)	(0.0089)	(0.0124)	(0.0106)	(0.079)	(0.0088)	(0.0124)	(0.0107)
Observations	1,081	8,844	8,474	8,474	8,474	9925	9,507	9,507	9,507

Note: All models include state-by-year fixed effects. A hybrid contract is a mixed contract including both cash rent and crop sharing. Standard errors in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

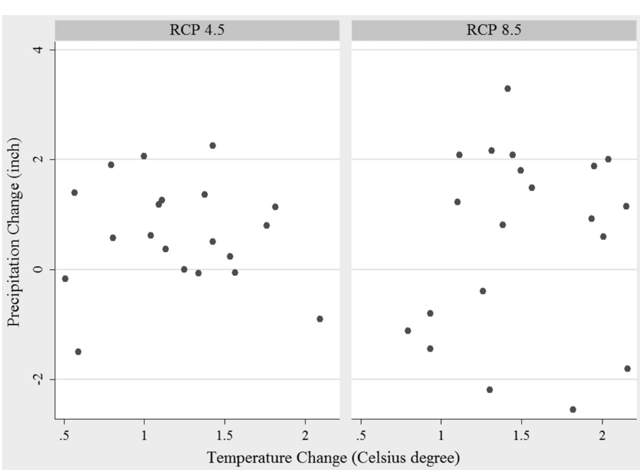

Fig. 1. Multi-model projected changes in 30-year averages of growing season total precipitation and average temperature for 2020–2049 relative to 1982-2011. Each dot represents a projection from a particular CMIP5 global climate model.

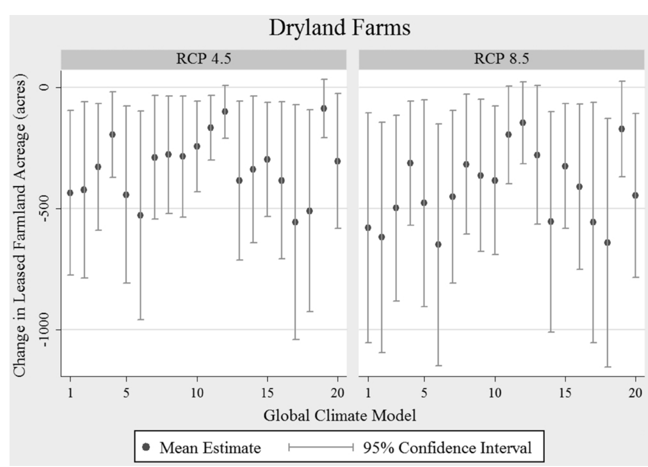

Fig. 2. Projected average changes in leased farmland acreage for PNW dryland wheat farms under RCPs 4.5 and 8.5 from 2012 to 2050 (Unit: acre).

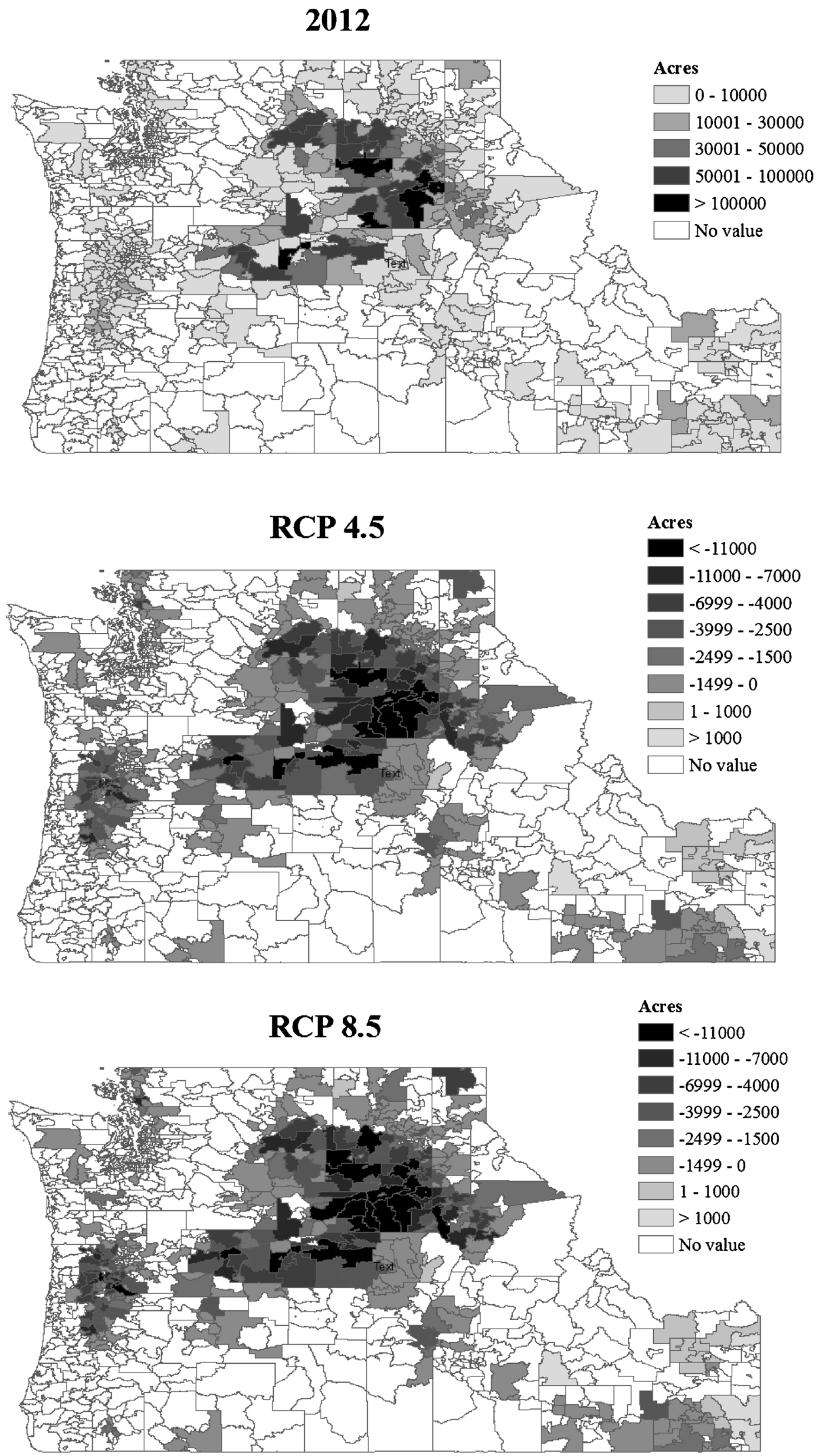

Fig. 3. Observed 2012 leased farmland acreage for PNW dryland wheat farms and changes in leased acreage from 2012 to 2050 under RCPs 4.5 and 8.5 by ZIP code.

probability of farmers choosing cash-rent contracts and a significant positive effect on choosing hybrid contracts. This occurs since increased precipitation variability increases production uncertainty and the use of crop-sharing contracts to spread risks between tenants and landowners.

We find that temperature and its variability have statistically insignificant effects on choice of leasing arrangement. One possible explanation is that in this study region with a cool and dry climate, precipitation variation is a driving force affecting wheat cropping systems and leasing arrangements, while temperature variation is small and not a great influence on leasing arrangements.

5.3. Sensitivity of results to alternative specifications - robustness checks

We utilize two alternative estimation approaches to check the robustness of the results. These involve an alternative stratification of the sample and an alternative construction of the climate variables. We first examine whether farmers under production contracts behave differently in terms of leasing compared to those without such a contract.[5] Thus we re-estimate the model by running two separate regressions for dryland wheat farms with and without production contracts. We find essentially the same signs for the marginal climate effects on leased land compared to estimation over the full dataset, although the marginal effects are larger under production contracts (columns 1 and 2 in Table 3) due to reduced income risk. We also find the estimated climate effects on farms without production contracts are largely unchanged compared to estimation over the full dataset (columns 3–5 in Table 3) because only a small number of farms (about 9%) in the full dataset are under production contracts. Thus, we conclude our results are basically robust to consideration of production contracts.

In a second robustness check, we use alternative climate variable constructions, employing much longer term 22-year moving averages.[6] Results in Table 3 show that there are no meaningful changes in the estimates of the climate variables on the extent of leased farmland acreage (column 6 in Table 3) and leasing arrangements (columns 7–9 in Table 3).

6. Land leasing implications of projected climate change

Now we turn to examination of the effect of projected future climate change on leased acreage. To do this we use 2050 projections from 20 of the Coupled Model Intercomparison Project Phase 5 (CMIP5) models under Representative Concentration Pathway (RCP) 4.5 and 8.0 indicating medium and high greenhouse-gas emission scenarios. The data used are those downscaled by Abatzoglou (2013)[7]. In doing this, we evaluate the regression equation for amount of land leasing in column 1 Table 2.

Fig. 1 summarize the climate change projections for the PNW averaged across the 20 global climate models. Temperatures are projected to increase by $+1.2^{\circ}$ C under RCP 4.5 and $+1.5^{\circ}$ C under RCP 8.5. Most climate models project precipitation increases with mean increase of + 16 mm under RCP 4.5 and + 14 mm under RCP 8.5.

Fig. 2 presents the 2050 leased acreage results. The resultant projection shows that leasing will become less common, decreasing by 23% and 29% under RCPs 4.5 and 8.5, respectively. However, also shown in Fig. 2, there is a wide band of results across the global climate model projections.

In Fig. 3, we show the regional distribution of changes in leased acreage under the average projections. There we find broad spatial heterogeneity with the largest increase in the Inland Pacific Northwest.

7. Conclusions

We examined the historical influences that climate has had on PNW dryland wheat farmland leasing and choice of contract terms and then projected changes in leased land acreage into the future under climate change. Our estimates show that increases in precipitation and temperature reduce leased farmland acreage and increase the use of cash-rent contracts, although temperature effects are statistically insignificant. In addition, increases in precipitation variability reduce the likelihood that farmers use cash-rent contracts. Our projection is that by 2050, leased acreage on average will decline by 23% under RCP 4.5 and 29% under RCP 8.5. Our findings on reduced leasing likely imply that future climate will lead to larger owner operated farm sizes.

Agriculture must adapt to ongoing and future climate change to feed the rapidly growing world population. The United Nations (2017) projects that the world's population will reach 11.2 billion in 2100, among which over 80% of the population will live in Africa and Asia. Although a variety of agricultural adaptations have been studied in the literature, including changes in planting dates, crop choices, seed varieties and land use, few studies examine the role of agricultural land rental market as an adaptation. It is important and policy-relevant for future research to further study the effects of land and other input markets on adaptation, especially for developing countries in Africa and Asia.

[5] A production contract is an agreement between a grower (farmer) and a contractor specifying that the grower will raise an agricultural commodity and that the contractor will provide certain inputs such as seed and fertilizer. The grower receives a payment or fee from the contractor, generally after delivery, which is usually less than the full market price of the commodity. The contractor gains the raised commodity at the end of the growing season. One advantage of production contracts is reducing income risk for growers.

[6] We use 22-year moving averages of temperature and precipitation because our weather data from Abatzoglou and Brown (2012)'s observed historical data begins in the year 1979.

[7] The specific global climate models included in this paper are: (1) CCSM4, (2) CSIRO-Mk3-6-0, (3) inmcm4, (4) IPSL-CM5A-LR, (5) IPSL-CM5A-MR, (6) IPSL-CM5B-LR, (7) MRI-CGCM3, (8) NorESM1-M, (9) bcc-csm1-1, (10) bcc-csm1-1-m, (11) BNU-ESM, (12) CanESM2, (13) CNRM-CM5, (14) GFDL-ESM2G, (15) GFDL-ESM2M, (16) HadGEM2-CC365, (17) HadGEM2-ES365, (18) MIROC5, (19) MIRC-ESM, (20) MIROC-ESM-CHEM. For more on these climate models, see Flato et al.(2013) in the latest IPCC report.

Conflicts of interest

The authors declare no conflict of interest.

Appendix A

Table A1
Coefficient estimates of covariates on leased farmland acreage and contract choice.

Variables	(1) Land leased in 1000 acres	(2) Choice of hybrid contract	(3) Choice of crop-sharing contract
Precipitation	−0.0676***	−0.0422**	−0.0839***
	(0.0148)	(0.0177)	(0.0221)
Precipitation squared	0.0006***	0.0005**	0.0008**
	(0.0002)	(0.0003)	(0.0003)
Temperature	0.4819***	0.1164	0.3636**
	(0.1238)	(0.1405)	(0.1830)
Temperature squared	−0.0417***	−0.0104	−0.0284**
	(0.0097)	(0.0109)	(0.0137)
C.V. precipitation	−0.0883	0.1249**	0.0918
	(0.0536)	(0.0492)	(0.0592)
C.V. temperature	0.0736	−0.0372	−0.0376
	(0.0550)	(0.0466)	(0.0571)
CRP and WRP programs	0.1012	−0.2337	0.2299
	(0.0780)	(0.1654)	(0.1535)
Classified as large farm	1.5392***	0.6307***	0.3055***
	(0.0687)	(0.0647)	(0.0769)
Farming experience	−0.0087***	−0.0016	−0.0027
	(0.0016)	(0.0021)	(0.0025)
Farming occupation	0.4068***	0.1834*	−0.0050
	(0.0498)	(0.1001)	(0.1145)
Slope	0.0027	−0.0016	0.0070
	(0.0049)	(0.0046)	(0.0057)
Soil organic content	−0.0225	−0.0248	−0.0356*
	(0.0147)	(0.0154)	(0.0193)
Sand content	−0.0025	−0.0187***	−0.0381***
	(0.0064)	(0.0039)	(0.0045)
Clay content	−0.0143	−0.0329***	−0.0871***
	(0.0101)	(0.0098)	(0.0125)
Soil loss tolerance factor	−0.0845	0.1616**	0.3455***
	(0.0780)	(0.0681)	(0.0802)
Intercept	0.7445	0.3796	0.0889
	(0.6047)	(0.6273)	(0.7957)
State-year fixed effects	Yes	Yes	Yes
R-squared	0.189	–	–
Log likelihood	–	−8010.8103	−8010.8103
Observations	9925	9507	9507

Notes: The base outcome in the multinomial logit model of contract choice is cash-rent contracts, so columns (2) and (3) report the coefficient estimates relative to an alternative scenario using cash-rent contracts. Standard errors are in parentheses. Standard errors in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

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